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**THE LINK BETWEEN INNOVATION
AND PRODUCTIVITY IN CANADIAN
MANUFACTURING INDUSTRIES**

*By Wulong Gu, Statistics Canada, and
Jianmin Tang, Industry Canada*

*Working Paper Number 38
November 2003*

Industry Canada Research Publications Program

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National Library of Canada cataloguing in publication data

Gu, Wulong, 1964-

The link between innovation and productivity in Canadian manufacturing industries
[electronic resource]

(Working paper ; no. 38)

Issued also in French under title: Le lien entre l'innovation et la productivité
dans les industries manufacturières.

Includes bibliographical references.

Issued also in print format.

Mode of access: WWW site of Industry Canada.

ISBN 0-662-34397-2

Cat. no. C21-24/38-2003E-IN

1. Manufacturing industries – Technological innovations – Canada.

2. Industrial productivity – Canada.

3. Technological innovations – Canada.

I. Tang, Jianmin, 1962-

II. Canada. Industry Canada.

III. Title.

IV. Series: Working paper (Canada. Industry Canada) ; no. 38.

HC120.T4G8 2003

338.'064'0971

C2003-980205-1

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ACKNOWLEDGMENTS

We would like to thank Zhiqi Chen, Pierre Mohnen, Randall Morck and Someshwar Rao for their very helpful comments and suggestions. Views expressed in this paper do not necessarily reflect those of Industry Canada or Statistics Canada.

ABSTRACT

Empirical studies commonly use research and development (R&D) to measure innovation and often find, especially in Canada, no strong link between productivity and innovation. In this paper, we model innovation as an unobservable latent variable that underlies four indicators: R&D, patents, technology adoption and skills. We find that these indicators are reasonably good measures of innovation for aggregate manufacturing. But the reliability of the indicators for innovation differs among individual industries. Only the skill indicator is a fairly good measure of innovation for all manufacturing industries. Our innovation indexes, based on the latent variable model, show that most manufacturing industries became more innovative over the 1980-97 period. The pace of innovation in the electrical and electronic products industry accelerated during the 1990s. In addition, we show that the new measure of innovation has a positive and statistically significant impact on productivity. It takes from one to three years, depending on the industry, for innovation to generate an impact on productivity.



1. INTRODUCTION

Innovation is a continuous process of the development and application of new ideas and technologies. It is the key driver of economic growth. Innovation in the information technology sector and throughout the economy has been the leading factor in the strong growth of the U.S. economy since the mid-1990s (Council of Economic Advisers, 2001). In addition, the pace of innovation has accelerated over the last decade. Globalization and the diffusion of information technology have enhanced competition, so that all firms need to become innovative to compete in this new and global economy. The climate and conditions for innovation have also changed. The linkages between industry and the science base are becoming more important. Information and communications technologies have played an important role in technology diffusion and the commercialization process. The dramatic shift in skill-biased technical change has increased the importance of skills to innovation.

This increased innovation is expected to have a positive and significant impact on productivity. However for Canada, this expectation has not been strongly supported in many empirical studies (see Mohnen, 1992 and Bernstein, 2002). In this paper, we argue that the lack of evidence for a strong link between productivity and innovation is due to incomplete measures of innovation. To support this argument, we first construct a comprehensive measure of innovation. Unlike most empirical studies that use a single indicator, usually research and development (R&D), to measure innovation, we model innovation as an unobservable latent variable that underlies four indicators: R&D propensity, measured as a percentage of output; patents per worker; technology adoption, measured as real investment in machinery and equipment; and skill intensity, measured as the employment share of workers with a university education.¹ We then examine the relationship between innovation and productivity in Canadian manufacturing industries and find a strong link between them.

2. MEASURING INNOVATION

Methodology for Measuring Innovation

Innovation has many dimensions. It has economic as well as social and cultural aspects, some of which are abstract and not susceptible to economic measurement.² Empirical analysis of innovation often uses a single indicator to measure it. The commonly used indicators are R&D propensity, patents per worker, technology adoption and skills intensity. However, none of them is a perfect measure of innovation.

R&D Propensity

To be innovative, firms need to invest in R&D to generate or adopt new products or processes in the marketplace. R&D expenditure as a percentage of output, or R&D propensity, is used to measure the input to the innovation process. As such, it is at best an imperfect indicator of the output of the innovation process, as not all R&D effort will generate outcomes; and, importantly, innovation can be undertaken in other forms, such as technology adoption.

Patents per Worker

To protect intellectual property rights, many firms patent their inventions. The number of patents, however, provides only a partial measure of the output of the innovation process. First, not all innovation ends with an invention. Second, some patents never find commercial applications. Third, the propensity to patent an invention varies across firms.³ Some companies do not use patents to protect intellectual property rights — they use trade secrets or copyrights instead.

Technology Adoption

New technologies must be adopted to have an impact on productivity.⁴ The measures of technology adoption include the number of new products and processes introduced and the share of output accounted for by these new products and processes. In this paper, we use real investment in machinery and equipment (M&E) per worker to measure technology adoption, as new technologies are often embodied in M&E.

Skill Intensity

Firms need to employ skilled workers to undertake R&D and adopt advanced technologies. There is well-documented evidence for the strong link between innovation and skilled labour (e.g., Bernstein; Morck and Yeung 2000; Rao, Ahmad, Horsman and Kaptein-Russell 2001). To measure the skilled-labour input to innovation, empirical analysis uses the employment share of scientists, engineers and other R&D professionals in total employment. In this paper, we use the employment share of workers with at least a university degree in total employment.

To capture various measurable aspects of innovation, empirical studies on innovation often use one of these indicators. However, as argued by Bernstein, no single indicator could possibly capture the multidimensional nature of the innovation process. In this paper, we take a different approach. We model innovation as an unobservable latent variable that underlies these four partial indicators of innovation. The estimated innovation measures should provide us with a more comprehensive measure than any one of these partial indicators.

Denote the measure of innovation by the variable ξ . It represents the unobservable latent variable that is to be estimated from four observable indicators of innovation: R&D propensity (x_1), number of patents per worker (x_2), the employment share of skilled labour (x_3), and real M&E investment per worker (x_4). The empirical relationship between the four innovation indicators and the latent innovation variable for an industry is modelled as follows:⁵

$$(1) \quad x_i = \lambda_i \xi + \delta_i, \quad (i = 1, 2, 3, 4),$$

where ξ is the latent variable representing innovation, x_i is the i th innovation indicator, λ_i is the coefficient of x_i on ξ and δ_i is the residual for x_i .

In the model, each innovation indicator is expressed as a multiple of the latent variable plus the residual. Assuming that the residual is orthogonal to the latent variable, we can write the covariance matrix among the four innovation indicators, Σ , as

$$(2) \quad \Sigma = \lambda \lambda' + \Theta,$$

where Θ is the covariance matrix of the residuals, δ .

The coefficients are estimated by minimizing the difference between the covariance matrix of the innovation indicators estimated from the sample and that determined by the model.

To examine the importance of an indicator as a measure of innovation, we estimate the reliability of the innovation indicator. The reliability of the indicator x_i for innovation is defined as the percentage of the variance in the indicator that is explained by the latent innovation variable.

$$(3) \quad \rho_{ii} = 1 - \frac{\theta_{ii}}{\lambda_i^2 + \theta_{ii}},$$

where θ_{ii} is the variance of δ_i .

The higher the reliability of an innovation indicator, the more informative the indicator is as a measure of innovation.

Using the parameter estimates, we can calculate the innovation measure of an industry as⁶

$$(4) \quad \hat{\xi} = \hat{\lambda} \hat{\Sigma}^{-1} x.$$

Clearly, the innovation measure is a weighted sum of the four indicators. The weights are given by $\hat{\lambda} \hat{\Sigma}^{-1}$, depending on the estimated coefficients and the variance and covariance matrices. For an indicator, the larger its estimated coefficient and the lower its variance, the higher its weight. However, the weight is also influenced by other indicators through its covariance with those indicators.

Results

We constructed innovation indexes for 15 manufacturing industries and total manufacturing over the 1980-97 period. The indexes allowed us to examine the innovation trends in the 15 industries and the total manufacturing sector.

Data for measuring innovation consist of time series for 15 manufacturing industries on R&D propensity, patent grants per worker, real M&E investment per worker and the employment share of workers with at least a university degree. The 15 manufacturing industries are listed in Table 1. Data for all variables are obtained from Statistics Canada, except for the data on the number of patent grants, which are obtained from the U.S. patent office.⁷ These represent the patents granted to Canadian industries by the United States.

Table 1
Industry Aggregation

Industry	1980 SIC
1. Food, Beverages and Tobacco	E10-E12
2. Rubber and Plastic Products	E15-E16
3. Textiles	E17-E24
4. Wood, Furniture and Fixtures	E25-E26
5. Paper and Allied Products	E27
6. Printing and Publishing	E28
7. Primary Metals	E29
8. Fabricated Metal Products	E30
9. Machinery	E31
10. Transportation Equipment	E32
11. Electrical and Electronic Products	E33
12. Non-metallic Mineral Products	E35
13. Refined Petroleum and Coal Products	E36
14. Chemical Products	E37
15. Other Manufacturing	E39
Total Manufacturing	E10-E39

To construct innovation measures for individual manufacturing industries and total manufacturing, we first estimate the latent variable model of innovation for those industries. The latent variable models for the 15 manufacturing industries are estimated simultaneously to improve the efficiency of the estimates. We start with the constraints that the coefficients on innovation indicators are the same across all industries and that the covariances among the residual terms of the four innovation indicators are all equal to zero ($\theta_{ij} = 0$, for $i \neq j, i, j = 1, 2, 3, 4$). We then gradually relax the constraints that are statistically most significant until the remaining constraints are not significant and the model has a good fit.⁸ Similarly, for total manufacturing, we estimate the model by imposing the constraint that the covariances among the residual terms of the four innovation indicators equal zero. Again, we gradually relax the constraints that are statistically most significant until the remaining constraints are not significant and the model has a good fit.

Table 2 presents the coefficient estimates for the 15 individual manufacturing industries and total manufacturing.⁹ For total manufacturing, all four indicators are correlated with innovation, and the correlation is highly significant statistically.¹⁰ This suggests that these four indicators are reasonably good measures of innovation for total manufacturing, although they are not perfect. It also indicates that technology generation, indicated by R&D and patents, and technology adoption, indicated by investment in M&E, are both important sources of innovation for aggregate manufacturing. To be innovative, firms must invest in R&D, or purchase new M&E that embody the latest technologies. As well, firms need to employ skilled workers to conduct R&D and adopt new technologies.

Table 2
Coefficient Estimates from the Latent Variable Model of Innovation

Industry	R&D	Patents	Skilled Labour	M&E Investment
4. Wood, Furniture and Fixtures	0.116 (0.316)	-0.185 (-0.101)	0.647* (9.777)	0.665* (10.958)
5. Paper and Allied Products	0.718* (12.295)	0.390 (1.649)	0.647* (9.777)	0.665* (10.958)
6. Printing and Publishing	0.718* (12.295)	-0.024 (-0.087)	0.647* (9.777)	0.665* (10.958)
12. Non-metallic Mineral Products	0.718* (12.295)	0.690* (10.422)	0.647* (9.777)	-0.126 (-0.788)
13. Refined Petroleum and Coal Products	0.718* (12.295)	-0.147 (-0.460)	0.647* (9.777)	0.665* (10.958)
14. Chemical Products	0.954* (5.250)	0.909* (4.832)	0.922* (4.954)	-0.222 (-0.901)
All Other Manufacturing Industries (nine industries)	0.718* (12.295)	0.690* (10.422)	0.647* (9.777)	0.665* (10.958)
Total Manufacturing	0.863* (4.444)	0.974* (5.483)	0.923* (4.982)	0.698* (3.261)

Notes: The estimates for the covariance matrix of the residual δ are not reported.
An asterisk indicates statistical significance at the 5 percent level.
The t-statistics are in parentheses.

These results are true for most manufacturing industries. However, for some, the correlation between the four innovation indicators and innovation differs significantly. Expenditure on R&D is not correlated with innovation for wood, furniture and fixtures, where the main source of innovation is investment in new equipment and skilled workers.

The technology adoption variable is not correlated with innovation for the chemical products industry, where innovation comes from its own R&D; the industry relies on its own technology for innovation. The same is true for the non-metallic mineral products industry. This result is a little surprising, but it is consistent with the evidence from the Statistics Canada 1999 Survey of Innovation, which shows that the percentage of firms in the non-metallic mineral products industry doing R&D or using patents to protect their intellectual property is above the average for total manufacturing firms, but below the average for total manufacturing firms in the acquisition of technologies (Tang, 2001).

For total manufacturing, patents are found to be a good indicator of innovation but not indicative of innovation for wood, furniture and fixtures, paper and allied products or printing and publishing. There are two main reasons for this result. First, these industries tend to rely more on technology adoption than on technology generation for innovation. Second, when they engage in technology generation, they tend to use trademarks, copyrights and other means to protect their intellectual property rights.

Finally, skilled workers are highly correlated with innovation for all industries. To be innovative, whether in technology generation or technology adoption, all industries must use skilled workers. This implies that unlike the other indicators, which are good for only some industries, skilled workers are a fairly good indicator of innovation for all manufacturing industries.

Table 3 presents the estimated reliability of R&D, patents, skilled workers and M&E investment as indicators of innovation, on the basis of Equation (3). It confirms what we have already learned from the coefficient estimates in Table 2. The four innovation indicators all provide good but imperfect measures of innovation for total manufacturing. Among the four indicators, M&E investment appears to be the least indicative of innovation. For electrical and electronic products, all four are indicative of innovation. For wood, furniture and fixtures, however, R&D and patents are not indicative of innovation. In contrast, R&D and patents provide good indicators of innovation for chemical products.

Table 3
Reliability of Innovation Indicators

Industry	R&D	Patents	Skilled Labour	M&E Investment
1. Food, Beverages and Tobacco	0.347	0.431	0.267	0.250
2. Rubber and Plastic Products	0.342	0.285	0.293	0.263
3. Textiles	0.677	0.621	0.365	0.589
4. Wood, Furniture and Fixtures	0.013	0.034	0.419	0.442
5. Paper and Allied Products	0.446	0.148	0.385	0.399
6. Printing and Publishing	0.431	0.001	0.416	0.510
7. Primary Metals	0.349	0.471	0.463	0.330
8. Fabricated Metals	0.518	0.481	0.409	0.418
9. Machinery	0.446	0.461	0.370	0.425
10. Transportation Equipment	0.318	0.393	0.499	0.415
11. Electrical and Electronic Products	0.901	0.839	0.743	0.789
12. Non-metallic Mineral Products	0.470	0.422	0.379	0.016
13. Refined Petroleum and Coal Products	0.424	0.021	0.342	0.367
14. Chemical Products	0.910	0.827	0.851	0.049
15. Other Manufacturing	0.945	0.674	0.220	0.716
Total Manufacturing	0.745	0.949	0.852	0.488

We use the coefficient estimates to construct an innovation measure for the 15 individual manufacturing industries and total manufacturing over the 1980-97 period. The innovation measure for an industry is the weighted sum of the four indicators for the industry. The weights are estimated on the basis of Equation (4). As discussed earlier, they are determined by the estimated coefficients and the estimated variance and covariance matrices. The normalized weights are presented in Table 4.¹¹ In general, the more significant an indicator, the greater its weight. However, there are some exceptions. For instance, for the printing and publishing industry, patents are not significant but are given the greatest weight.¹² This happens because the error term of the patent variable in this industry is significantly correlated with the error terms of skilled workers and M&E investment.

Table 4
Weights for Innovation Indicators

Industry	R&D	Patents	Skilled Labour	M&E Investment
1. Food, Beverages and Tobacco	0.385	0.500	0.075	0.039
2. Rubber and Plastic Products	0.355	0.189	0.314	0.142
3. Textiles	0.351	0.284	0.107	0.258
4. Wood, Furniture and Fixtures	0.104	0.264	0.317	0.315
5. Paper and Allied Products	0.331	0.038	0.291	0.339
6. Printing and Publishing	0.012	0.424	0.171	0.393
7. Primary Metals	0.039	0.068	0.518	0.374
8. Fabricated Metal Products	0.159	0.385	0.113	0.343
9. Machinery	0.273	0.417	0.271	0.039
10. Transportation Equipment	0.260	0.137	0.449	0.153
11. Electrical and Electronic Products	0.418	0.249	0.148	0.185
12. Non-metallic Mineral Products	0.282	0.422	0.248	0.049
13. Refined Petroleum and Coal Products	0.374	0.038	0.282	0.306
14. Chemical Products	0.453	0.251	0.266	0.030
15. Other Manufacturing	0.764	0.095	0.021	0.120
Total Manufacturing	0.147	0.581	0.190	0.081

The innovation indexes for individual and total manufacturing industries are reported in Table 5. Clearly, total manufacturing as a whole became more innovative over the 1980-97 period. All industries, with the exception of rubber and plastic, non-metallic mineral, and refined petroleum and coal products, became more innovative. The industry with the largest increase in innovation activities was electrical and electronic products, followed by textiles, other manufacturing and chemical products. Indeed, for electrical and electronic and chemical products, innovation accelerated during the late 1980s and the 1990s and increased more than 40 percent over that period. A similar trend toward an increased pace in

innovation for high-tech industries in the 1990s is also found in the U.S. high-tech sector (Council of Economic Advisers).

The increase in innovation activities in other manufacturing is understandable, given that instruments makes up the greatest part of this industry. But, the large increase in innovation activities for textiles during this period is surprising. However, this result is consistent with the finding that textiles is one of the most innovative industries in terms of product and process innovation (Le and Tang, 2001) because it invests heavily in M&E and adopts advanced technologies (Baldwin and Da Pont, 1993).

The innovation measure for the refined petroleum and coal products industry shows the largest variation over the 1980-97 period. This is due to volatility in the underlying data on nominal gross domestic product (GDP) and skilled workers for the industry. To reduce the impact of this volatility on the regression results in our pool estimation, we exclude this industry from our regression analysis in the next section.

Table 5
Innovation Indexes, by Industry (1980 = 1.00)

Industry	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1. Food, Beverages and Tobacco	1.00	1.07	1.25	1.25	1.19	1.23	1.42	1.25	1.56	1.33
2. Rubber and Plastic Products	1.00	0.53	0.86	0.89	1.16	1.04	1.14	0.81	1.09	0.64
3. Textiles	1.00	1.46	1.48	1.35	1.85	2.35	1.83	2.15	2.26	2.65
4. Wood, Furniture and Fixtures	1.00	1.06	1.14	1.14	1.21	1.28	1.14	1.34	1.47	1.34
5. Paper and Allied Products	1.00	1.34	1.08	1.28	1.28	1.28	1.28	1.58	1.66	2.12
6. Printing and Publishing	1.00	1.01	1.09	1.06	1.24	1.16	1.28	1.38	1.32	1.38
7. Primary Metals	1.00	0.93	0.97	0.99	1.26	1.07	1.01	1.13	1.01	1.23
8. Fabricated Metal Products	1.00	1.09	1.03	1.33	1.44	1.43	1.59	1.30	1.16	1.36
9. Machinery	1.00	0.96	1.10	1.15	1.10	1.23	1.42	1.45	1.14	1.24
10. Transportation Equipment	1.00	1.01	1.10	1.13	1.09	1.13	1.12	1.29	1.38	1.38
11. Electrical and Electronic Products	1.00	1.26	1.57	1.80	1.85	2.07	2.15	2.00	2.09	2.04
12. Non-metallic Mineral Products	1.00	0.90	0.93	0.94	1.10	1.10	1.13	0.73	1.15	0.76
13. Refined Petroleum and Coal Products	1.00	2.08	1.82	1.00	1.11	0.90	0.74	0.80	0.77	2.57
14. Chemical Products	1.00	1.10	1.34	1.13	1.13	1.28	1.23	1.34	1.23	1.24
15. Other Manufacturing	1.00	0.94	1.19	1.26	1.32	1.68	2.17	2.09	1.79	1.87
Total Manufacturing	1.00	1.09	1.21	1.21	1.29	1.35	1.37	1.38	1.43	1.49

Table 5 (continued)

Industry	1990	1991	1992	1993	1994	1995	1996	1997
1. Food, Beverages and Tobacco	1.25	1.45	1.30	1.42	1.48	1.84	1.63	1.77
2. Rubber and Plastic Products	0.84	0.81	0.67	0.79	1.16	0.85	1.02	0.78
3. Textiles	1.72	2.02	2.39	3.48	2.65	2.78	3.02	2.70
4. Wood, Furniture and Fixtures	1.12	0.88	0.72	1.14	1.15	1.35	1.06	1.40
5. Paper and Allied Products	1.63	1.57	1.86	1.89	1.63	1.69	1.68	1.85
6. Printing and Publishing	1.33	1.10	1.24	1.44	1.52	1.32	1.39	1.52
7. Primary Metals	1.24	1.15	1.37	1.66	1.13	1.33	1.23	1.23
8. Fabricated Metals	1.19	1.26	1.89	1.83	1.74	1.66	1.67	1.74
9. Machinery	1.21	1.27	1.37	1.50	1.47	1.42	1.62	1.42
10. Transportation Equipment	1.36	1.36	1.49	1.56	1.39	1.62	1.45	1.52
11. Electrical and Electronic Equipment	2.15	2.35	2.46	2.59	2.89	2.93	3.02	2.89
12. Non-metallic Mineral Products	0.53	0.75	0.86	0.86	0.95	1.15	0.60	0.93
13. Refined Petroleum and Coal Products	1.11	0.77	0.80	0.87	0.72	0.69	0.74	0.87
14. Chemical Products	1.34	1.45	1.66	1.61	1.76	1.73	1.87	1.87
15. Other Manufacturing	2.06	1.98	2.13	2.30	2.55	2.74	2.43	2.43
Total Manufacturing	1.50	1.54	1.68	1.76	1.74	1.78	1.79	1.85

3. THE LINK BETWEEN INNOVATION AND PRODUCTIVITY

In this section, we examine the relationship between innovation and productivity, using the innovation index constructed above. For that purpose, we use a panel data set of 14 industries (the refined petroleum and coal products industry is excluded) over the 1980-97 period to estimate the following specification:

$$(5) \quad \ln(LP_{it}) = \alpha_i + \sum_{T=1984}^{1997} \beta_T D_{Tt} + \beta_2 U_{it} + \beta_3 S_{it} + \beta_4 \ln(k_{it}) \\ + \beta_5 \hat{\xi}_{it}(-1) + \beta_6 \hat{\xi}_{it}(-2) + \beta_7 \hat{\xi}_{it}(-3) + \varepsilon_{it},$$

where LP_{it} is labour productivity, defined as GDP per hour worked, for industry i in year t ;

D_T is the year dummy for year t ;

U_{it} is capacity utilization for industry i in year t ;

S_{it} is the employment share of large-sized firms (500+ employees);

k_{it} is the capital/labour ratio, defined as the ratio of capital stock to hours worked, for industry i in year t ;

$\hat{\xi}_{it}(-1)$, $\hat{\xi}_{it}(-2)$ and $\hat{\xi}_{it}(-3)$ are the innovation measures for industry i in year $t-1$, $t-2$ and $t-3$, respectively;¹³ and

ε_{it} is the error term for industry i in year t .

In the specification, we introduce industry fixed effects, α_i , to control for unobservable and time-invariant industry characteristics that affect labour productivity. We also include year dummies to control for macro-economic factors (such as business cycles and exchange rate movements) that are common to all industries. In all regressions, we allow for heteroskedasticity between industries and first-order autocorrelation — AR(1) — within industries. The impact of innovation on productivity may vary across industries, so we allow the choice of the lagged innovation indexes, $\hat{\xi}_{it}(-1)$, $\hat{\xi}_{it}(-2)$ and $\hat{\xi}_{it}(-3)$, to differ across industries. Depending on the statistical fit to the data, an industry can have one, two or all three of the lagged innovation indexes.

Data for the employment share of large-sized firms, capacity utilization and capital/labour ratio are from Statistics Canada. Capital stock includes non-residential structure, M&E, inventory and land. The employment share of large-sized firms is obtained from the Statistics Canada Annual Survey of Manufacturers. The large-sized firms are defined here as firms with more than 500 employees.

Table 6 presents the regression results on the effects of innovation on productivity. To improve efficiency, all 14 manufacturing industries are estimated simultaneously by pool estimation.¹⁴ After controlling for factors such as capital intensity and capacity utilization, innovation is found to have a positive and statistically significant impact on productivity for all manufacturing industries. However, the time it takes for innovation to raise productivity differs across industries. For example, it takes one year for innovation to have a positive impact on productivity for electrical and electronic products; two years for machinery; two to three years for chemical products; and three years for food, beverages and tobacco, and wood, furniture and fixtures.

To examine the impact of innovation on productivity, it is important to recognize the difference in time lags across industries. When the time lags are assumed to be the same across industries, innovation is found to have no significant impact on productivity (see Table 8).¹⁵ This is true when only one or two of the three lagged innovation variables are used.

The relationship between innovation, especially R&D, and productivity has been widely examined. Many studies find a significant link between innovation and productivity (e.g. Griliches 1998 and Griliches and Mairesse, 1998, using R&D for the United States; Nadiri and Prucha, 1990, using R&D for the United States and Japan; and Verspagen, 1999, using patents for France, Germany and the United Kingdom). However, studies in Canada as surveyed by Mohnen and Bernstein do not find a strong link between R&D and productivity.¹⁶ This is supported in a recent study conducted by Baldwin and Sabourin (2001) using survey data and is consistent with our regression results. In Tables 9 to 13, we report the estimation results when the innovation index is replaced by each of its indicators. Tables 9 to 12 are based on the same regression as Table 6, except that innovation is measured by R&D, patents, skilled workers and M&E investment, respectively. Innovation in Table 13 is measured by R&D, but with the assumption that the time pattern is the same for all industries. The results show that all R&D, patent, and M&E investment-related variables are insignificant. For skilled workers, only the three-year lag, which applies to only four industries, was significant.

This lack of evidence for the positive impact of R&D and other indicators on productivity appears to be due to the fact that they provide only a partial and incomplete measure of innovation. Canadian firms not only generate their own technology, but they also rely on purchased technology for innovation. This is especially true for foreign-controlled firms.¹⁷ In this paper, we have constructed an innovation measure that captures both technology generation and technology adoption. Using the more comprehensive measure, we find that innovation has a positive and statistically significant impact on productivity in Canadian manufacturing.

Table 6
Pool Estimation of the Effects of the Innovation Index on Productivity,
with Different Lags of Innovation Across Industries

Industry	Size	Capacity Utilization	Capital Intensity	Innovation (-1)	Innovation (-2)	Innovation (-3)	AR(1)
Coefficients	0.108 (0.59)	0.006 (6.40)*	0.076 (2.18)*	0.023 (2.60)*	0.014 (2.11)*	0.024 (1.95)**	0.909 (29.57)*
1. Food, Beverages and Tobacco	√	√	√			√	√
2. Rubber and Plastic Products	√	√	√	√	√		√
3. Textiles	√	√	√	√	√	√	√
4. Wood, Furniture and Fixtures	√	√	√			√	√
5. Paper and Allied Products	√	√	√	√			√
6. Printing and Publishing	√	√	√	√			√
7. Primary Metals	√	√	√		√		√
8. Fabricated Metal Products	√	√	√	√			√
9. Machinery	√	√	√		√		√
10. Transportation Equipment	√	√	√	√	√		√
11. Electrical and Electronic Products	√	√	√	√			√
12. Non-metallic Mineral Products	√	√	√		√		√
14. Chemical Products	√	√	√		√	√	√
15. Other Manufacturing	√	√	√		√		√

Number of Observations: 196; Durbin-Watson Statistics: 1.87; Adjusted R-square: 0.98.

Notes: √ indicates the estimated coefficient that applies to the industry.

* indicates statistical significance at the 5 percent level, and ** indicates statistical significance at the 10 percent level.

The t-statistics are in parentheses.

The regression includes industry and year dummies; the estimates of the coefficients on the dummy variables are not reported.

Table 7
Pool Estimation of the Effects of the Innovation Index on Productivity,
with Different Lags of Innovation Across Industries: First-difference Method

Industry	Size	Capacity Utilization	Capital Intensity	Innovation (-1)	Innovation (-2)	Innovation (-3)
Coefficients	0.022 (0.11)	0.007 (10.45)*	0.079 (2.32)*	0.043 (5.08)*	0.022 (3.19)*	0.032 (2.60)*
1. Food, Beverages and Tobacco	✓	✓	✓			✓
2. Rubber and Plastic Products	✓	✓	✓	✓	✓	
3. Textiles	✓	✓	✓	✓	✓	✓
4. Wood, Furniture and Fixtures	✓	✓	✓			✓
5. Paper and Allied Products	✓	✓	✓	✓		
6. Printing and Publishing	✓	✓	✓	✓		
7. Primary Metals	✓	✓	✓		✓	
8. Fabricated Metal Products	✓	✓	✓	✓		
9. Machinery	✓	✓	✓		✓	
10. Transportation Equipment	✓	✓	✓	✓	✓	
11. Electrical and Electronic Products	✓	✓	✓	✓		
12. Non-metallic Mineral Products	✓	✓	✓		✓	
14. Chemical Products	✓	✓	✓		✓	✓
15. Other Manufacturing	✓	✓	✓		✓	
Number of Observations: 196; Durbin-Watson Statistics: 1.56; Adjusted R-square: 0.47.						

Notes: ✓ indicates the estimated coefficient that applies to the industry.

* indicates statistical significance at the 5 percent level.

The t-statistics are in parentheses.

The regression includes industry and year dummies; the estimates of the coefficients on the dummy variables are not reported.

Table 8
Pool Estimation of the Effects of the Innovation Index on Productivity,
with Same Lags of Innovation Across Industries

Industry	Size	Capacity Utilization	Capital Intensity	Innovation (-1)	Innovation (-2)	Innovation (-3)	AR(1)
Coefficients	0.155 (0.82)	0.005 (5.83)*	0.085 (2.39)*	0.003 (0.44)	0.006 (0.81)	0.006 (0.92)	0.915 (30.37)*
1. Food, Beverages and Tobacco	✓	✓	✓	✓	✓	✓	✓
2. Rubber and Plastic Products	✓	✓	✓	✓	✓	✓	✓
3. Textiles	✓	✓	✓	✓	✓	✓	✓
4. Wood, Furniture and Fixtures	✓	✓	✓	✓	✓	✓	✓
5. Paper and Allied Products	✓	✓	✓	✓	✓	✓	✓
6. Printing and Publishing	✓	✓	✓	✓	✓	✓	✓
7. Primary Metals	✓	✓	✓	✓	✓	✓	✓
8. Fabricated Metals	✓	✓	✓	✓	✓	✓	✓
9. Machinery	✓	✓	✓	✓	✓	✓	✓
10. Transportation Equipment	✓	✓	✓	✓	✓	✓	✓
11. Electrical and Electronic Products	✓	✓	✓	✓	✓	✓	✓
12. Non-metallic Mineral Products	✓	✓	✓	✓	✓	✓	✓
14. Chemical Products	✓	✓	✓	✓	✓	✓	✓
15. Other Manufacturing	✓	✓	✓	✓	✓	✓	✓
Number of Observations: 196; Durbin-Watson Statistics: 1.88; Adjusted R-square: 0.98.							

Notes: ✓ indicates the estimated coefficient that applies to the industry.

* indicates statistical significance at the 5 percent level.

The t-statistics are in parentheses.

The regression includes industry and year dummies; the estimates of the coefficients on the dummy variables are not reported.

Table 9
Pool Estimation of the Effects of R&D on Productivity,
with Different Lags of R&D Across Industries

Industry	Size	Capacity Utilization	Capital Intensity	R&D (-1)	R&D (-2)	R&D (-3)	AR(1)
Coefficients	0.139 (0.73)	0.005 (5.85)*	0.089 (2.53)*	0.018 (1.01)	0.031 (1.26)	-0.007 (-0.29)	0.922 (32.70)*
1. Food, Beverages and Tobacco	✓	✓	✓			✓	✓
2. Rubber and Plastic Products	✓	✓	✓	✓	✓		✓
3. Textiles	✓	✓	✓	✓	✓	✓	✓
4. Wood, Furniture and Fixtures	✓	✓	✓			✓	✓
5. Paper and Allied Products	✓	✓	✓	✓			✓
6. Printing and Publishing	✓	✓	✓	✓			✓
7. Primary Metals	✓	✓	✓		✓		✓
8. Fabricated Metals	✓	✓	✓	✓			✓
9. Machinery	✓	✓	✓		✓		✓
10. Transportation Equipment	✓	✓	✓	✓	✓		✓
11. Electrical and Electronic Products	✓	✓	✓	✓			✓
12. Non-metallic Mineral Products	✓	✓	✓		✓		✓
14. Chemical Products	✓	✓	✓		✓	✓	✓
15. Other Manufacturing	✓	✓	✓		✓		✓

Number of Observations: 196; Durbin-Watson Statistics: 1.89; Adjusted R-square: 0.98.

Notes: ✓ indicates the estimated coefficient that applies to the industry.

* indicates statistical significance at the 5 percent level.

The t-statistics are in parentheses.

The regression includes industry and year dummies; the estimates of the coefficients on the dummy variables are not reported.

Table 10
Pool Estimation of the Effects of Patents on Productivity,
with Different Lags of Patents Across Industries

Industry	Size	Capacity Utilization	Capital Intensity	Patent (-1)	Patent (-2)	Patent (-3)	AR(1)
Coefficients	0.159 (0.83)	0.005 (5.79)*	0.086 (2.33)*	0.013 (0.66)	-0.006 (-0.37)	0.003 (0.13)	0.918 (32.34)*
1. Food, Beverages and Tobacco	✓	✓	✓			✓	✓
2. Rubber and Plastic Products	✓	✓	✓	✓	✓		✓
3. Textiles	✓	✓	✓	✓	✓	✓	✓
4. Wood, Furniture and Fixtures	✓	✓	✓			✓	✓
5. Paper and Allied Products	✓	✓	✓	✓			✓
6. Printing and Publishing	✓	✓	✓	✓			✓
7. Primary Metals	✓	✓	✓		✓		✓
8. Fabricated Metals	✓	✓	✓	✓			✓
9. Machinery	✓	✓	✓		✓		✓
10. Transportation Equipment	✓	✓	✓	✓	✓		✓
11. Electrical and Electronic Products	✓	✓	✓	✓			✓
12. Non-metallic Mineral Products	✓	✓	✓		✓		✓
14. Chemical Products	✓	✓	✓		✓	✓	✓
15. Other Manufacturing	✓	✓	✓		✓		✓

Notes: ✓ indicates the estimated coefficient that applies to the industry.

* indicates statistical significance at the 5 percent level.

The t-statistics are in parentheses.

The regression includes industry and year dummies; the estimates of the coefficients on the dummy variables are not reported.

Table 11
Pool Estimation of the Effects of Skills on Productivity,
with Different Lags of Skills Across Industries

Industry	Size	Capacity Utilization	Capital Intensity	Skills (-1)	Skills (-2)	Skills (-3)	AR(1)
Coefficients	0.156 (0.84)	0.005 (6.03)*	0.083 (2.35)*	0.006 (0.39)	0.018 (1.36)*	0.047 (2.03)*	0.918 (33.03)*
1. Food, Beverages and Tobacco	√	√	√			√	√
2. Rubber and Plastic Products	√	√	√	√	√		√
3. Textiles	√	√	√	√	√	√	√
4. Wood, Furniture and Fixtures	√	√	√			√	√
5. Paper and Allied Products	√	√	√	√			√
6. Printing and Publishing	√	√	√	√			√
7. Primary Metals	√	√	√		√		√
8. Fabricated Metal Products	√	√	√	√			√
9. Machinery	√	√	√		√		√
10. Transportation Equipment	√	√	√	√	√		√
11. Electrical and Electronic Products	√	√	√	√			√
12. Non-metallic Mineral Products	√	√	√		√		√
14. Chemical Products	√	√	√		√	√	√
15. Other Manufacturing	√	√	√		√		√

Number of Observations: 196; Durbin-Watson Statistics: 1.90; Adjusted R-square: 0.98.

Notes: √ indicates the estimated coefficient applies to the industry.

* indicates statistical significance at the 5 percent level.

The t-statistics are in parentheses.

The regression includes industry and year dummies; the estimates of the coefficients on the dummy variables are not reported.

Table 12
Pool Estimation of Effects of the M&E Investment on Productivity,
with Different Lags of M&E Investment Across Industries

Industry	Size	Capacity Utilization	Capital Intensity	M&E (-1)	M&E (-2)	M&E (-3)	AR(1)
Coefficients	0.104 (0.54)	0.005 (5.99)*	0.082 (2.29)*	0.014 (0.86)	0.009 (0.67)	0.019 (0.84)	0.920 (32.74)*
1. Food, Beverages and Tobacco	√	√	√			√	√
2. Rubber and Plastic Products	√	√	√	√	√		√
3. Textiles	√	√	√	√	√	√	√
4. Wood, Furniture and Fixtures	√	√	√			√	√
5. Paper and Allied Products	√	√	√	√			√
6. Printing and Publishing	√	√	√	√			√
7. Primary Metals	√	√	√		√		√
8. Fabricated Metals	√	√	√	√			√
9. Machinery	√	√	√		√		√
10. Transportation Equipment	√	√	√	√	√		√
11. Electrical and Electronic Products	√	√	√	√			√
12. Non-metallic Mineral Products	√	√	√		√		√
14. Chemical Products	√	√	√		√	√	√
15. Other Manufacturing	√	√	√		√		√

Number of Observations: 196; Durbin-Watson Statistics: 1.90; Adjusted R-square: 0.98.

Notes: √ indicates the estimated coefficient applying to the industry.

* indicates statistical significance at the 5 percent level.

The t-statistics are in parentheses.

The regression includes industry and year dummies; the estimates of the coefficients on those dummy variables are not reported.

Table 13
Pool Estimation of the Effects of R&D on Productivity,
with Same Lags of R&D Across Industries

Industry	Size	Capacity Utilization	Capital Intensity	R&D (-1)	R&D (-2)	R&D (-3)	AR(1)
Coefficients	0.154 (0.81)	0.005 (5.86)*	0.086 (2.43)*	0.007 (0.49)	-0.006 (-0.40)	-0.012 (-0.86)	0.917 (32.24)*
1. Food, Beverages and Tobacco	✓	✓	✓	✓	✓	✓	✓
2. Rubber and Plastic Products	✓	✓	✓	✓	✓	✓	✓
3. Textiles	✓	✓	✓	✓	✓	✓	✓
4. Wood, Furniture and Fixtures	✓	✓	✓	✓	✓	✓	✓
5. Paper and Allied Products	✓	✓	✓	✓	✓	✓	✓
6. Printing and Publishing	✓	✓	✓	✓	✓	✓	✓
7. Primary Metals	✓	✓	✓	✓	✓	✓	✓
8. Fabricated Metal Products	✓	✓	✓	✓	✓	✓	✓
9. Machinery	✓	✓	✓	✓	✓	✓	✓
10. Transportation Equipment	✓	✓	✓	✓	✓	✓	✓
11. Electrical and Electronic Products	✓	✓	✓	✓	✓	✓	✓
12. Non-metallic Mineral Products	✓	✓	✓	✓	✓	✓	✓
14. Chemical Products	✓	✓	✓	✓	✓	✓	✓
15. Other Manufacturing	✓	✓	✓	✓	✓	✓	✓

Number of Observations: 196; Durbin-Watson Statistics: 1.87; Adjusted R-square: 0.98.

Notes: ✓ indicates the estimated coefficient that applies to the industry.

* indicates statistical significance at the 5 percent level.

The t-statistics are in parentheses.

The regression includes industry and year dummies; the estimates of the coefficients on the dummy variables are not reported.

4. CONCLUSION

In this paper, we find that technology generation and technology adoption are both important sources of innovation. To be innovative, firms must invest in R&D or purchase new M&E that embody the latest technologies. As well, they need to employ skilled workers to conduct R&D and adopt new technologies.

Over the 1980-97 period, almost all industries became more innovative. For total manufacturing, the pace of innovation does not appear to have accelerated in the 1990s. But, for chemical, and electrical and electronic products, the pace of innovation accelerated during the 1990s.

In Canada, many studies use R&D alone as a measure of innovation and find little evidence of a positive impact by innovation on productivity. Using a comprehensive measure of innovation that captures both technology generation and technology adoption, we find a strong and positive relationship between innovation and productivity. However, the length of time that it takes for innovation to have a positive and significant impact on productivity differs across industries. For some industries, it takes only one year; for others, it takes two to three years.

NOTES

- 1 In this paper, we focus on technological innovation. The set of indicators is the commonly used set for technological innovation, but it is by no means exhaustive.
- 2 Bernstein (2002) and Morck and Yeung (2000) provide excellent reviews of the many dimensions of innovation.
- 3 For some firms, patents are used as a tool to prevent competitors from patenting. As documented in Bernstein, and Morck and Yeung, some firms engage in patent thickening to prevent their competitors from patenting, although these patents have little economic value.
- 4 Rao, Ahmad, Horsman and Kaptein-Russell (2001) call technology adoption applied innovation, to distinguish it from technology invention, which they call fundamental innovation.
- 5 A similar model is used by Lanjouw and Schankerman (1999) to construct a quality index of patented innovation based on four indicators.
- 6 Note that the estimated variance of the latent variable, $\text{var}(\hat{\xi})$, is standardized to be unity.
- 7 We do not use patent data from Canadian sources because of quality concerns. Canadian patent laws came into effect in 1989. Post-1989 patent filing activities have changed dramatically and may not be comparable to those before 1989. For a detailed discussion, see Demers, Rafiquzzaman and Smith (2001).
- 8 To measure the fitness, we use a number of fit statistics, including chi-square, root mean square error of approximation, and the expected cross-validation index (Joreskog and Sorbom, 1999).
- 9 The estimated variance and covariance matrices, which are diagonal for some industries but not for others, as well as the fit statistics, are not reported.
- 10 The estimated coefficients may be interpreted as correlation coefficients between the innovation indicators and the latent innovation variable.
- 11 By normalization, we mean that the sum of the weights is equal to one.
- 12 Note, however, that although the weight is greater, its overall contribution to the innovation measure is very small, as this industry has virtually no patent grants.
- 13 The non-lagged innovation variable is found to have no statistically significant impact on productivity.
- 14 For a robustness check, we also estimate Equation (5) in the first-difference form. We first-difference the equation to remove industry fixed effects and include year dummies. The results are similar (see Table 7). The remaining analysis will be based on regressions in the level form.
- 15 The regression models for Table 6 and Table 8 are non-nested. The J test does not reject the hypothesis that the model for Table 6 is preferred to the model for Table 8 (for the J test, see Davidson and Mackinnon, 1993, pp. 381-95).

- 16 This is especially true for empirical studies based on time series data. Empirical studies based on cross-section data are more likely to find a strong and significant relationship between innovation and productivity. For a discussion on the possible reasons for this difference in the context of model specifications, see Crépon, Duguet and Mairesse (1998).
- 17 Because of the large presence of foreign-controlled firms in Canada, which are subject to the so-called "headquarters" effect (centralization) of R&D spending by multinationals, Canadian firms spend, on average, significantly less on R&D when compared to their counterparts in other G7 countries, especially the United States. Tang and Rao (2001) show that foreign-controlled firms in Canada are doing less R&D, but they are adopting technologies from their parents and are more productive than Canadian-controlled firms.

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